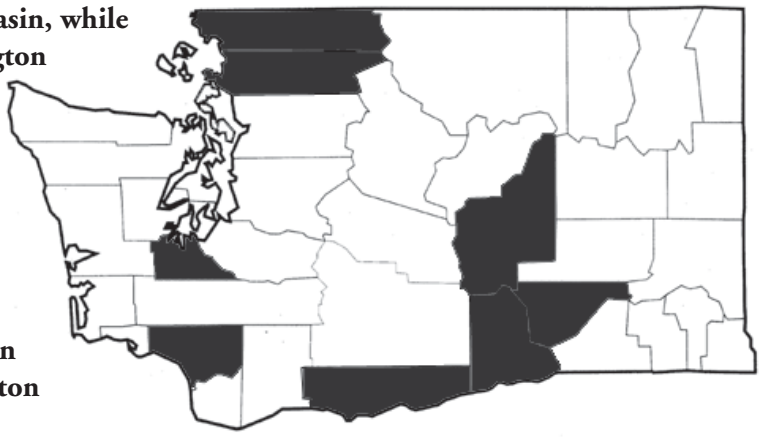
Crop Profile for Carrots in Washington

Production Facts

- Washington state ranks first in the U.S. in production of processing carrots and fourth for fresh market carrots (1). Overall, Washington ranks second to California in production of carrots.
- Washington produces approximately 33% of the processing carrots grown in the U.S. and 3% of the fresh carrots (1).
- In 1998, 6,500 acres of processing carrots and 3,000 acres of fresh market carrots were harvested in Washington (2). About 2% of this carrot acreage was grown using organic methods. The total cash value of the carrot crop was more than $28 million.
- Approximately 134 farms grew carrots in 1997 (3). Of these, 106 were irrigated.
- Production costs for Imperator-type carrots were $2,347 per acre and $2,090 for Chantenay-type carrots in the south Columbia Basin in 2000 (4).

Production Regions

Carrots are grown commercially in both eastern and western Washington. The leading counties are Benton, Franklin, Grant, and Klickitat in eastern Washington and Cowlitz, Skagit, Thurston, and Whatcom in western Washington. Over the past decade, acreage has dramatically increased in eastern Washington, particularly in the Columbia Basin, while western Washington acreage has remained constant. West of the Cascade Mountains the crop is grown with natural rainfall. Fields in eastern Washington are irrigated.



Cultural Practices

Carrot cultivar trial in the Columbia Basin.

Carrots (*Daucus carota*) are a biennial crop grown as an annual for its root. It is a cool season vegetable, but will tolerate warm temperatures early in the growing season. Roots attain their optimal color when the air temperature is 60 to 70° F. Root color can deepen rapidly when temperatures are within this range three weeks before harvest, but color can decline at higher temperatures. The orange color of carrots is due to presence of carotenes, which human metabolism breaks down to vitamin A. Carrots provide 30% of the vitamin A in the U.S. diet (5).

Three types of carrots are important commercially in Washington state for the fresh market and processing: Imperator carrots, Chantenay carrots, and baby carrots.

Imperator carrots have long, slender roots. This type of carrot is used for both fresh market and processing and is often referred to in Washington state as "slicers" or dual purpose carrots. Roots of Imperator type carrots are typically 8 to 10 inches long, with a diameter of 1-1/2 inch. Maturity ranges from early to late. In recent years, "cut and peel" carrots have become an important part of the carrot market. "Cut and peel" carrots are produced using Imperator cultivars. Roots are cut into 2- to 2-1/4-inch lengths and peeled in steel cylinders to resemble small carrots.

Chantenay-type carrot.

Chantenay carrots have thick, relatively short roots. In Washington state, this type of carrot is grown for processing as "dicer" carrots. Chantenay carrots are harvested late, when their roots average 6 to 7 inches in length and about 3 inches in diameter.

A few growers in the Columbia Basin produce true baby carrots.

All Imperator and "cut and peel" carrot cultivars currently grown are hybrids, while open-pollinated cultivars are used for growing Chantenay and true baby carrots. Some of the most commonly planted Imperator cultivars grown in eastern Washington are 'Apache,' 'Avenger,' 'Discovery,' 'Gold Pride,' 'Legend,' 'Orlando Gold,' 'Plato,' and 'Prime Cut' (6). "HM 4302,' and 'Sugar Snax 54,' are standard "cut and peel" cultivars. 'Red Core Chantenay' is the most widely grown Chantenay type carrot. 'Amsterdam Minicore' is grown as a baby carrot. Small-scale growers generally favor Nantes type carrots. Nantes carrots have roots that are cylindrical in cross section and medium in length. 'Bolero,' 'Mokum,' and 'Presto' are some of the more popular cultivars.

High yield potential, uniformity, smooth roots, and good color and flavor are desirable characteristics for both processing and fresh market carrots. It is also important that carrot cultivars do not bolt prematurely and that their roots do not crack or split when harvested mechanically.

All processing carrots in Washington state are grown under contract. The contracts specify harvest dates, amount supplied, and specifications for root size and quality. Growers, however, make their own decisions on production and pest management practices. The grower also generally selects which cultivar to plant.

There is a great difference in the scale of production among Washington state carrot growers (6). Small-scale growers typically plant less than 20 acres of carrots annually and many plant less than 5 acres. Large-scale growers plant more than 100 acres of carrots. A number of large-scale growers plant more than 500 acres each year. Most small-scale operations are located in western Washington, while the large-scale operations are east of the Cascades.

A majority of large-scale carrot growers in Washington state grow processing carrots. Many of these growers plant only for processing, while others grow both processing and fresh market carrots. Small-scale carrot operations grow exclusively for the fresh market. All large-scale growers and a majority of small-scale growers produce carrots on land they own as well as additional land they lease.

In eastern Washington, most carrots are grown on 40- to 42-inch beds; some growers use beds that are 72 inches wide. Carrots are always direct seeded and never thinned. Carrot seeds are small in comparison to other vegetable seeds, and slow to emerge. A fine seedbed is essential and the soil must be kept moist to prevent crusting. Germination may take as long as two weeks in cool weather. In eastern Washington, carrots may be seeded from April until June. Harvesting takes place from July until mid-November.

Although carrots are often grown on sandy soils, they tolerate a wide range of soil types as long as the upper 30 inches of soil is uniform and free of barriers to root growth. In soils that are too heavy, roots may be misshapen and therefore unmarketable. Carrots are heavy feeders and nutrient availability must be sufficient to support the crop.

Shaping carrot beds.

Excess nitrogen should be avoided as it results in lush tops that are more vulnerable to disease. Information gathered in soil tests and plant analysis is used to plan fertility programs for individual fields.

Carrot seed varies from 175,000 to 400,000 per pound. Seed is sown at a rate of 1,000,000 seed per acre for fresh market varieties and at lower rates for the larger processing types (7). Higher densities, up to 1.7 million seeds per acre, are used for plantings for the "cut and peel" market. Seed is commonly sown in 6 or 8 lines per bed. Correct spacing is essential to ensure uniformly sized roots. Both natural and pelleted seed are used. For natural seed, many growers use converted Planet Jr. planters utilizing a random flow distribution of seed drop (8). Stanhay belt planters with split shoes are often used for precision planting of pelleted seed. Other precision planters used by carrot growers include vacuum seeders, such as Gespardo and Stanhay. Natural seed is used in vacuum seeders.

Machine-harvesting carrots.

A uniform water supply is essential for good color and root formation (8). In low rainfall areas, proper irrigation is critical during stand establishment. Frequent application of water is often necessary to prevent soil crusting and dehydration of young seedlings. Soil type does not affect the total amount of water needed, but does dictate frequency of water application. Lighter soils need more frequent irrigation, but less water per application. Carrots should not be under moisture stress at any time. A lack of adequate moisture will result in poor emergence and growth. If significant wet-dry cycles occur, roots may split or crack and develop poor color. Such carrots are generally unmarketable. Over-irrigation may increase the incidence of disease.

Carrots are harvested in a number of ways, depending on their intended final use and the size of the operation. Some small-scale growers harvest by hand and bunch the carrots with the tops intact. On a larger scale, Imperator carrots for fresh market or processing are often harvested with self-propelled multirow harvesters, which undercut and lift carrots from the ground by their tops using a system of belts (8). After the tops are sheared off, the roots are dropped into a waiting truck running along side the harvester. For the fresh market, the roots are then hauled to a shed for washing, grading, sizing, and packing. In the shed, carrots are generally washed and cooled in clean water treated with chlorine. For processing, roots are washed in cold water before entering the processing plant. Chantenay carrots grown for processing are typically topped and crowned in the field before harvesting. These carrots are then harvested with a coulter pick-up or modified potato harvester. In the Columbia Basin, typical yields of Imperator carrots are about 29 tons per acre and Chantenay carrots yield about 40 tons per acre (4). On average, 40 to 80 percent of all carrots in a field are harvested and packed or processed; those that are damaged by insects, diseases, or are cracked, deformed or off-color are culled. Culled carrots may be used for juice, but more commonly they are fed to livestock.

Topping carrots prior to harvest.

IPM Strategies

All carrot growers in Washington state use some IPM practices in their operation to control diseases, nematodes, insects, and weeds (6). Field selection is one practice used by all large- and small-scale growers as a pre-plant practice. Disease, nematode, and weed problems are the reasons most often cited by growers. Most growers use soil

testing, as well as cropping history, to select fields and to determine whether chemical treatment is necessary. Field scouting is used to help manage insect pests by 86% of the large-scale carrot growers in Washington state, and by 71% of growers for disease and weed management (6).

Other in-season IPM practices include mechanical cultivation and hand weeding for weed control, timing of planting for disease and weed control, and irrigation and fertility management for disease and insect control. Post-harvest practices include crop rotation, sanitation, and cover crops. Economic thresholds are used by 43% of Washington state carrot growers to determine when or whether to treat for insect pests and nematodes (6).

Most carrot acreage in Washington state is grown following conventional production practices. The majority of large-scale growers use conventional practices exclusively, while the remainder have both a conventional and organic component in their operation. The majority of small-scale growers follow organic production practices.

Diseases

Diseases are the main pest concern of large-scale carrot growers in Washington state. Alternaria and Cersospora leaf blights, cavity spot, and forking and stubbing are the most important diseases of carrots in Washington state (9). Powdery mildew, aster yellows phytoplasma, white mold, viruses, bacterial leaf blight, and damping-off also cause losses. The organisms that cause damping-off are widespread and attack young and germinating seedlings of many crop plants (10). Seed treatment with a chemical such as thiram is commonly used to prevent losses.

Most large-scale carrot growers report that disease problems have increased in severity over the past five years (6). Those disease which have increased the most are leaf blights, cavity spot, and forking and stubbing. Cavity spot and forking and stubbing are caused by soil-borne organisms that tend to build up in the soil after carrots are grown. The close spacing needed to produce "cut and peel" carrots has tended to increase disease pressure from foliar diseases such as leaf blights, powdery mildew, and white mold.

Leaf Blights
Alternaria dauci and *Cercospora carotae*

Alternaria leaf symptoms.

Two disease organisms, *Alternaria dauci* and *Cercospora carotae*, can cause leaf blight in carrots. Alternaria leaf blight often appears first on older leaves in early fall (10). Symptoms include dark brown to black, irregularly shaped lesions on leaves and petioles. These initially have a yellow border. As the lesions grow together the entire leaf may be killed. Leaves weakened by blight may break when gripped by harvesters, leaving the roots in the ground. Spring infection may occur when large amounts of inoculum are present. Seedlings can develop damping-off from early infections.

Symptoms of Cercospora leaf blight are usually most severe and obvious along the leaf margin (10). Lesions are initially brown with a yellow halo. As the lesions enlarge, leaves become yellow and curled. Under heavy disease pressure, severe loss of foliage can occur. The lesions caused by these two diseases are easily confused. Lesions caused by *Alternaria* are generally more irregularly

shaped and darker in color than those caused by *Cercospora*.

Alternaria and *Cercospora* overwinter on crop refuse and alternate hosts (10). They may also be seed-borne. Wet conditions favor *Alternaria* and spores may be spread through the air or in splashing water.

Chemical Control

Chlorthalonil (Bravo) and iprodione (Rovral) are the standard chemicals used to control leaf blights in Washington state (8). Copper sprays, which are considered less effective, are used on a small percent of the acreage.

In 1996, 2,900 pounds of chlorothalonil was applied in Washington to control diseases of carrots (11). It is the most widely used fungicide in the state.

Chemical	Target Pests	% Acreage Treated	Rate (lb ai/a)	# App's	Application Method
Chlorothalonil	Alternaria, Cercospora	55	1.2	2.5	Air, ground
Copper	Alternaria, Cercospora, Xanthomonas	5	1	3	Air
Iprodione	Alternaria	20	0.6	1.5	Air, chemigation

Cultural Control

Seed that is known to be free of *Alternaria* and *Cercospora* should be selected for planting. Seed can also be treated with hot water to kill these organisms. Crop rotation to non-host crops for at least 1 year and turning under residue following carrot harvest can help reduce losses. Irrigation should be scheduled so that foliage is dry by nightfall. Carrot cultivars differ in their susceptibility to leaf blights. 'Orlando Gold' is reported to be resistant to *Alternaria* (10).

Cavity Spot
Pythium violae

Cavity spot is one of the most important diseases of carrots in Washington state. Small, horizontal lesions appear on roots when they are

Cavity spot symptoms.

nearing harvest stage (10). Individual lesions are usually less than 0.5 inch long. Soil generally adheres to the lesions and they are sometimes first noticed when the roots are harvested and washed. If numerous, the lesions make the carrots unmarketable, especially for the fresh market.

The fungus that causes cavity spot is favored by cool soil temperatures (8). The severity of the disease is probably dependent on the number of overwintering spores present in the soil.

Chemical Control

Metalaxyl (Ridomil) is applied to control cavity spot and forking and stubbing caused by *Pythium* spp. Approximately 60% of the carrot acreage in Washington state is treated (8).

Chemical	Target Pests	% Acreage Treated	Rate (lb ai/a)	# App's	Application Method
Metalaxyl	Pythium	60	0.3	1.5	Ground, chemigation

Cultural Control

Field selection and crop rotation are practiced to minimize losses due to cavity spot. Over irrigation needs to be avoided. Raised beds are useful in keeping soil in the root zone well-drained. In some trials, 'Caropride,' 'Navajo,' 'Orlando Gold,' and 'Six Pak' have shown greater than average resistance (10).

Forking and Stubbing
Pythium spp.

Forking and stubbing of carrot roots may be caused by several species of *Pythium*. The fungus kills young tap roots less than 2 weeks after germination, reducing root length and/or causing multiple roots (8). A number of other factors, including compacted soil and nematodes, can also cause forking and stubbing.

The severity of the disease is related to the number of overwintering oospores in the soil (8). Wet soil conditions also favor the disease.

Chemical Control

Metalaxyl (Ridomyl) is applied as a preplant chemical treatment in fields with a known history of *Pythium* related problems. (See Metalaxyl table under "Cavity Spot," above.)

Cultural Control

As with cavity spot, field selection and crop rotation are useful practices in managing forking and stubbing caused by *Pythium*. Proper irrigation management is also important.

Aster Yellows Phytoplasma

The new leaves of carrots infected with aster yellows are yellow, stunted, and deformed (10). Older leaves may have a reddish or purplish color and dormant buds in the crown may develop giving the plant a witches' broom appearance. Roots frequently are deformed and have numerous, hair-like lateral roots.

Aster yellows is caused by a phytoplasma which overwinters on host plants, including many weeds (10). Among the susceptible crop plants grown in Washington state are potatoes and squash. The organism is spread by leafhoppers.

Chemical Control

No direct chemical control is used for aster yellows. Leafhoppers and weeds can be managed using pesticides.

Cultural Control

Cultural methods including insect and weed control are useful in minimizing losses from aster yellows (10). Infected plants may also be removed from the field as soon as they are detected. Carrot fields are at greater risk if planted near areas where weeds or other plants provide a reservoir for leafhoppers and phytoplasma organisms.

Powdery Mildew
Erysiphe polygoni

Older leaves of plants infected with powdery mildew may be covered with a white, powdery growth (8). It can spread to the younger leaves causing the entire plant to be infected. Infected foliage can become brittle and yellow, and can eventually die.

The fungus survives the winter on carrots and other hosts, including wild carrot (8). Spores are spread through the air. Infection is favored by high humidity.

Chemical Control

Sulfur is applied at the rate of 20 pounds per acre by air to control powdery mildew. About one quarter of the carrot acreage in Washington is treated with sulfur (8).

Cultural Control

Leaf trimming is moderately effective as a tool for controlling powdery mildew. Leaves are trimmed when rows begin to close to increase air flow and reduce humidity within the canopy. Selecting cultivars with tolerance to the disease and maintaining good plant vigor are recommended and practiced control methods.

Chemical	Target Pests	% Acreage Treated	Rate (lb ai/a)	# App's	Application Method
Sulfur	Powdery mildew	25	20	2.5	Air

White Mold
Sclerotinia sclerotiorum

White mold, or cottony rot, may infect carrots at any stage of growth. Roots may decay before leaves begin to wilt and collapse. Infection is characterized by a cottony, white mold. On or inside the white mold are black, irregularly shaped sclerotia, which are the resting structures of the fungus. The disease is sometimes severe on stored carrots (10). Losses can also occur in transit.

The fungus that causes white mold overwinters in the soil and requires moist conditions to become active. It has a wide host range that includes many crop plants, including beans, potatoes, and cucurbits.

Chemical Control

Benomyl (Benlate) is occasionally used as a chemical control for white mold in the field. Post harvest dips with a chemical such as thiabendazole (Mertect) can reduce post-harvest losses. A very small number of acres are treated.

Cultural Control

Washington carrot growers avoid white mold by rotating to non-host plants (e.g., cereals, onions) and managing irrigation carefully. They avoid over-watering, which causes high relative humidity and prolonged periods of leaf wetness. Some growers trim leaves to allow better air cirulcation and reduce humidity levels. Planting cultivars with stocky, upright foliage and increasing spacing between rows have a similar effect.

Storage bins are cleaned and disinfected between seasons (10). Storage conditions that include a temperature near freezing and humidity of 85 to 90% will help minimize losses.

Motly Dwarf
(complex of carrot mottle virus and carrot red leaf luteovirus)

Symptoms of motly dwarf are similar to aster yellows and include rosetting, stunting, and yellowish and reddish leaf margins (10). Roots are not malformed as with aster yellows.

This disease is a complex of two disease organisms, carrot mottle virus and carrot red leaf luteovirus, which are transmitted by the carrot willow aphid (10). Both the organisms and the vector can overwinter on wild carrots and willow.

Chemical Control

No direct chemical control is used for motly dwarf. Aphid populations should not be allowed to build up on carrots (10). Some growers use insecticides to help manage aphids. (See "Aphids" section under "Insect Pests.")

Cultural Control

Insect and weed control are useful in minimizing aster yellows. Late plantings may be more susceptible to infection (10).

Nematodes

In eastern Washington, nematodes are important pests of carrots. Large-scale growers consider nematodes to be second only to diseases in seriousness (6). Over the past five years, nematode problems have increased in severity for many large-scale carrot growers. Root-knot is the most common nematode pest. Root-lesion nematode may be a problem in some carrot fields.

Root-Knot Nematode
Meloidogyne hapla

Northern root-knot nematodes, *Meloidogyne hapla,* are very damaging to carrots. The Columbia root-knot nematode, *M. chitwoodi*, is not an economic problem on carrots (10). Symptoms of root-knot nematode damage are usually noticed first on above ground parts of the carrot plant and often appear as localized areas of stunted plants. Infected roots are typically forked and deformed. Numerous knots can be found on the main root and secondary roots. Root-knot nematodes attack many crops, including alfalfa, potato, and sugar beet, as well as many weeds.

Root-knot nematode symptoms.

Field sampling is an important tool in managing root-knot nematodes. Before planting, take soil samples with sufficient lead time to take appropriate management procedures if necessary (10). Sampling in the fall for planting the following spring is an excellent strategy.

Chemical Control

Statewide, as much as 3/4 of the carrot acreage is fumigated with dichloropropene (Telone II) or metam sodium (Vapam) to control nematodes (8). These chemicals also control certain insect pests and weeds.

Chemical	% Acreage Treated	Rate (lb ai/a)	Timing	# App's	Application Method
Dichloropropene	70	300	Pre-plant	1	Ground
Metam sodium	10	127	Pre-plant	1	Ground, chemigation

Cultural Control

Field selection, cover crops, and crop rotation are widely used to minimize losses from nematodes (6). These methods, however, are only moderately effective in controlling nematodes. Soil sampling, for example, does not always reveal the presence of nematodes.

Insect Pests

Aphids and leafhoppers are the most important insect pests of carrots in Washington (6), causing damage mainly by transmitting diseases to the crop. Others include cutworms, armyworms, and wireworms. Seed corn maggots are an occasional pest of carrots in the Columbia Basin. The larvae feed on germinating seeds, causing a reduction in plant stand. In western Washington, carrot rust fly is troublesome. In general, insects are less of a problem than diseases or nematodes for large-scale growers (6). For small-scale growers, however, insects are a major concern.

Aphids

various species, including
Cavariella aegopodii and *Myzus persicae*

Several aphid species are pests of carrots in Washington state. Among the most common and troublesome are the carrot aphid, *Cavariella aegopodii*, and the green peach aphid, *Myzus persicae*. These pests feed on the foliage, but the primary concern of growers is the transmission of diseases, such as motly dwarf.

The carrot aphid is pale yellow in color (12). Winged forms are pale yellow or green marked with black. The wingless forms of the green peach aphid are pale green in color. Winged forms have a black head and thorax. Willow is the primary host.

Chemical Control

Chemicals used to control aphids include diazinon, endosulfan (Thiodan),

and malathion (8). Malathion and endosulfan are each used on about 1/2 of the carrot acreage in the state. These materials also control leafhoppers and certain other insect pests.

Chemical	Target Pests	% Acreage Treated	Rate (lb ai/a)	# App's	App. Method
Diazinon	Aphids, rust fly, wireworms	10	2	1	Air
Endosulfan	Aphids, leafhoppers armyworms, cutworms	40	0.75	1	Air
Malathion	Aphids, leafhoppers	50	0.5	2	Air

Cultural Control

There are no effective cultural controls for aphids in carrots.

Leafhoppers
Macrostelles fascifrons

The six-spotted leafhopper is considered to be among the most important insect pests of carrots in Washington (8). This insect is a vector of the phytoplasma that causes aster yellows. It is a grayish green leafhopper about 1/4-inch long with six black spots on the top of the head (12). Leafhoppers overwinter on perennial weeds.

Chemical Control

Endosulfan (Thiodan), esfenvalerate (Asana), and malathion are the primary insecticides used to control leafhoppers (8). Of these chemicals, esfenvalerate and malathion are considered to be the most effective.

Chemical	Target Pests	% Acreage Treated	Rate (lb ai/a)	# App's	Application Method
Endosulfan	Aphids, leafhoppers armyworms, cutworms	40	0.75	1	Air
Esfenvalerate	Leafhoppers, cutworms	25	0.04	2	Air
Malathion	Aphids, leafhoppers	50	0.5	2	Air

Cultural Control

No effective cultural method is available to control leafhoppers. Weed control is used to reduce the reservoir of leafhoppers and phytoplasma.

Cutworms and Armyworms
various species

Cutworm larvae feed at or below the soil surface at night and hide during the day (12). Small plants may be killed and the leaves of older plants eaten. When full grown cutworms are about 1 inch long. They are variable in color, but are usually gray, brown, or black. Armyworms are a sporadic pest that feeds on carrot leaves during the day. The larvae are green, reddish, or black caterpillars, 1-1/2 to 2 in. long. They are a very sporadic pest, but can do considerable damage when present in large numbers.

Chemical Control

Cutworms are controlled primarily using endosulfan (Thiodan), esfenvalerate (Asana), and methomyl (Lannate) (8). Carbaryl (Sevin) is applied as a bait for cutworms. It is considered less effective than the other chemicals. Armyworms are controlled using endosulfan and methomyl.

Chemical	Target Pests	% Acreage Treated	Rate (lb ai/a)	# App's	Application Method
Carbaryl	Cutworms	5	1	1	Ground
Endosulfan	Aphids, leafhoppers armyworms, cutworms	40	0.75	1	Air
Esfenvalerate	Leafhoppers, cutworms	25	0.04	2	Air
Methomyl	Amyworms, cutworms	10	1	1	Air

Cultural Control

Weed control and sanitation can help reduce cutworm populations.

Wireworms
various species

Wireworms are a pest of many crops in Washington state, including carrots. The adults, known as click beetles, do little or no damage (12). The larva feed on roots and bore holes that can make carrots unmarketable. Wireworms require 2 to 6 years to mature, overwintering at a depth of 12 to 24 inches in the soil. They are light brown in color and about 1 inch long when fully mature.

Because the female beetles fly very little, infestations do not spread rapidly from field to field. Growers should determine the presence or absence of wireworms in the field before using any control measures.

Chemical Control

Diazinon is used on about 10% of the carrot acreage in Washington as a treatment for wireworms (8). Dichloropropene (Telone), a chemical commonly applied as a preplant treatment to control nematodes, also controls wireworms.

Chemical	Target Pests	% Acreage Treated	Rate (lb ai/a)	# App's	Application Method
Diazinon	Aphids, rust fly, wireworms	10	2	1	Ground, air

Cultural Control

Crop rotation is an important practice in controlling wireworms (12). Populations tend to build up in fields where grains or vegetable crops are grown. Weedy conditions also favor wireworms. If possible, growers select fields with no history of wireworm problems. Soil sampling can be used to check for the presence of wireworms.

Carrot Rust Fly
Psila rosae

The carrot rust fly can be a pest of carrots in western Washington. Maggots of the rust fly damage plants by eating the fibrous secondary roots and tunneling in larger roots (13). Mature larva are dusty, straw colored maggots from 1/8 to 1/4 inch long (12). Tunnels in the roots are often filled with rust red frass.

Chemical Control

Diazinon can be used to control rust fly. It is applied in the seed furrow at planting. (See Diazinon table under "Wireworms," above.)

Cultural Control

Field selection is the most commonly used cultural method for controlling carrot rust fly. Fields with a previous history of rust fly, soils with high organic content, and areas adjacent to brush or woods favor rust fly infestations. Row covers are an effective method for controlling carrot rust fly, but are practical only on small fields.

Weeds

Weeds reduce yields of carrots by direct competition for nutrients, water, and space. Weed control is especially critical early in the season for the formation of properly shaped roots, but it remains important throughout the growing season. Unlike many more robust vegetable crops, carrots require nearly complete weed control for successful commercial production. Weeds adversely affect carrot quality and, late in the season, make harvesting difficult. Weeds can also act as hosts to insect pests, nematodes, and diseases of carrots.

Annual and Perennial Broadleaves and Grasses

More than 20 different weeds are considered important pests of carrots (8). Pigweeds (*Amaranthus* spp.), lambsquarters (*Chenopodium album*), groundsel (*Senecio* spp.), and shepherdspurse (*Capsella bursa-pastoris*) are annual broadleaf weeds of economic significance in carrot fields across the state. In eastern Washington, kochia (*Kochia scoparia*), nightshades (*Solanum* spp.), Russian thistle (*Salsola iberica*), mallow (*Malva* spp.), and fleabane (*Erigeron* spp.) are serious weeds. Purslane (*Portulacea oleracea*), chickweed (*Stellaria* spp.), and knotweed (*Polygonum* spp.) are more prevalent in western Washington. The most important annual grasses are barnyardgrass (*Echinochloa crus-galli*) and foxtails (*Setaria* spp.). Canada thistle (*Cirsium arvense*), quackgrass (*Agropyron repens*), and horsetail (*Equisetum* spp.) are widespread perennial weeds.

Mature redroot pigweed.

Volunteer potato and volunteer cereals can be troublesome weeds in fields where these crops are grown in rotation. When present, dodder (*Cuscuta* spp.), a parasitic annual weed, can be a particular problem for carrot growers. Dodder plants consist of rootless, leafless stems that encircle and penetrate carrot foliage, diverting host nutrients (10). Warm temperatures and full sunlight favor dodder. Seeds of dodder can remain viable in the soil for 20 years.

Chemical Control

Relatively few herbicides are registered for use on carrots. In Washington state, trifluralin (Treflan), fluazifop-P-butyl (Fusilade DX), and linuron (Lorox) are the most widely used herbicides for weed control in carrots (8). Linuron and trifluralin control many annual broadleaves and grasses. Linuron is considered an especially important component of weed control programs in carrots. It is used primarily as a pre-plant treatment. Linuron is applied to 95% of the carrot crop in Washington state. About 65% of the acreage is treated with trifluralin as a pre-plant treatment by ground. Fluazifop-P-butyl, applied post-emergence by ground, is effective on most annual grasses and some perennial grasses. It is applied to about 45% of the carrot acres in Washington. Sethoxydim (Poast) is used post-emergence to control annual grasses on 10% of the carrot acreage.

Although the herbicides listed will control most weeds in carrots, it is rare that any single herbicide will control all weeds in a crop at any one time. Some combination of chemicals, therefore, is the usual practice. For example, trifluralin may be applied pre-plant and linuron applied post-emergence in the same field to control a broad spec-

trum of weeds. If grasses were a problem, fluazifop-P-butyl or sethoxydin might also be applied post-emergence.

Of all the chemical pesticides used on carrots, linuron is applied in the greatest amount. In 1996, 11,300 pounds of linuron were used on carrots in Washington state (11). A total of 3,200 pounds of trifluralin and 600 pounds of fluazifop-P-butyl were applied during the same year.

Stale seedbeds are sometimes used when selective weed control practices are limited (14). Success depends on controlling the first flush of emerging weeds before planting or crop emergence, and on minimal soil disturbance once the crop is established. Paraquat (Gramoxone Extra) and glyphosate (Roundup) are among the herbicides that can be used in such a program. Flaming is another option. Metribuzin (Sencor) can be used as a post-emergence herbicide for carrots. However, this chemical may injure certain carrot cultivars. A list of sensitive cultivars in Washington state is not currently available.

Soil fumigation is used to control nematodes and soilborne diseases. Metam sodium also controls weeds and can reduce the need for herbicides. However, soil fumigation is not justified on the basis of weed control alone nor does it adequately control weeds in most situations.

Volunteer potatoes in a carrot field.

Chemical	% Acreage Treated	Rate (lb ai/a)	Timing	# App's	App. Method
Fluazifop-P-butyl	45	0.12	Post-emergence	1	Ground
Linuron	95	0.73	Pre-plant, post-emergence	1 – 1.5	Ground
Sethoxydim	10	0.2	Post-emergence	1	Ground
Trifluralin	65	0.81	Pre-plant	1	Ground

Cultural Control

Cultivation is a key component of weed control. All carrot acreage in Washington state is cultivated (8). Most carrot growers cultivate at least once during the growing season, in addition to the cultivation that takes place when the field and seed beds are prepared. Cultivation also helps prevent sunburned or green carrots by throwing soil over the roots (14). Hand weeding is used on 90% of the carrot acreage (8). Hand weeding is used mainly to control large weeds that have escaped other methods of control. When present, volunteer potatoes must be removed by hand. Crop rotation is used on a majority of the carrot acres and irrigation management is also used as a tool for weed control. Irrigation management is useful in controlling certain weeds that thrive in moist conditions, such as barnyardgrass and some species of *Equisetum*. Other cultural control practices employed for weed control include field selection and timing of planting. Crop and weed removal is used to control dodder. Dodder should be removed before seeds have developed. Field scouting is an integral part of all weed control programs in Washington state.

The efficacy of non-chemical control practices is limited. Cultivation, for example, is only moderately effective in controlling weeds by itself, except between rows. The high plant density in carrot fields limits the use of mechanical cultivation and hand weeding for control of in-row weeds. Cultivation is limited to the center of the bed, the shoulders, and the furrows. Hand weeding is effective in removing troublesome weeds, but is costly and may remove carrots along with weeds. Flaming is used to control newly emerged weeds prior to crop emergence. It is not effective in controlling large weeds or perennials and cannot be used in row once the carrot crop has emerged.

Pest Control Issues

While all carrot growers in Washington State use non-chemical techniques in their production, chemical pesticides are an important component of IPM programs for controlling diseases, nematodes, insects, and weeds. The loss of chemical pesticides would have a tremendous effect on carrot production. The impact on yield if all herbicides were lost is estimated to be a decrease of 60% statewide (9). If all nematicides were lost, yields statewide would be reduced by an estimated 40%. The loss of fungicides and insecticides would each reduce yields by 30%.

Since so few herbicides are registered for use on carrots, the loss of any single chemical would be significant. The loss of linuron, in particular, would be disastrous to the Washington carrot industry. The impact on total carrot yield in the state for this one herbicide would be a loss of 35% (9). No other chemical currently registered can be used both pre-plant and post-emergence for control of weeds in carrots.

Mechanical cultivation would be the main substitute for lost herbicides. Cost and the availability of labor would limit the use of hand weeding in carrots. Hand weeding costs approximately $50 per acre (4). Non-chemical control practices are already a part of every integrated weed control program for carrots, but are most effective when combined with herbicide applications. Carrots are well adapted for effective, economical weed control with chemicals. As a result, the use of herbicides is standard practice in nearly all carrot acreage. Chemical weed control is not a substitute for pre-plant cultivation to kill emerging weeds. However, with proper use and timing, herbicides are usually so effective that weeds are not a serious problem.

Only two chemicals, dichloropropene and metam sodium, are used in Washington state to control nematodes. The loss of either material would severely limit the options available to growers. Growers are already using a variety of non-chemical alternatives, including crop rotation, field selection, and cover crops. These methods alone do not ensure that carrots will not be adversely affected by nematodes.

Because relatively few fungicides are used on carrots, the loss of individual materials would critically impact the industry, since effective alternatives, whether chemical or non-chemical, may not be available (8). For example, the loss of metalaxyl, which has no effective alternative against *Pythium*-induced diseases such as cavity spot and forking and stubbing, would result in losses of 25%. Losses could well be greater in the future. Cavity spot and forking and stubbing are among the diseases that are increasing in severity in Washington state (6). The loss of sulfur would result in a yield loss of 5% statewide since there are no alternatives for control of powdery mildew. Loss of iprodione for managing leaf blights would result in a yield loss of approximately 10%, since the alternatives, chlorothalonil and copper, are considered less effective in controlling *Alternaria*.

The impact of losing insecticides is difficult to predict. Chemical control methods are considered essential for outbreaks of insect pests (8). The transmission of diseases by uncontrolled insects could well increase diseases such as aster yellows and motly dwarf. If endosulfan, which is used primarily to control aphids and leafhoppers, were lost, an estimated yield loss of 17% would result. The alternatives, esfenvalerate and parathion, are considered less effective. In Washington state, endosulfan is also used to control occasional insect pests, such as armyworms. In years when armyworms are abundant, the loss of this material might cause even greater yield losses.

Carrot growers consider the loss of chemical pesticides a critical pest control issue. The loss of mevinphos and parathion has made leafhopper and aphid control more difficult (15). Few new chemicals are being registered for use on carrots. Registration of additional pesticides to assist disease, insect, and weed control is a priority to growers.

The possible elimination of organophosphate and carbamate pesticides concerns carrot growers. Among the insecticides commonly used in Washington State are two organophosphates, diazinon and malathion, and two carbamates, carbaryl and methomyl. The loss of these materials would limit the control options available to grow-

ers. For example, malathion is the most widely used insecticide for control of aphids and leafhoppers, the two most important insect pests of carrots in Washington. Although carrot rust fly and wireworms are only occasional pests, diazinon is the only material currently being used to control these insects. Production losses in Washington state are estimated to be 25% of overall production if organophosphate and carbamate materials were eliminated (16). Soil borne insects account for the majority of these potential losses.

A majority of both large- and small-scale carrot growers conduct their own on-farm research (6). Disease and insect management research, cultivar trials, and fertility studies are the most common type of grower conducted research in Washington state. With the exception of cultivar trials, there are currently no on-going university or Department of Agriculture research programs focusing on carrots. The research needs most often cited by growers are related to disease management. These needs include evaluation of methods of testing for soil-borne diseases, such as cavity spot, seed treatments, and information on resistant cultivars. Both large- and small-scale growers need pest management information related to organic production.

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Use pesticides with care. Apply them only to plants, animals, or sites listed on the label. When mixing and applying pesticides, follow all label precautions to protect yourself and others around you. It is a violation of the law to disregard label directions. If pesticides are spilled on skin or clothing, remove clothing and wash skin thoroughly. Store pesticides in their original containers and keep them out of the reach of children, pets, and livestock.

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